The place of genetic diversity in adapting forests to climate change

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INRA
SCIENCE & IMPACT

EFIATLANTIC & IEFC annual meeting
Edinburgh May 10, 2017

An answer to climate change : study the within population genetic variability of adaptive traits

1. Populations, not the species as a whole, are the adaptation units to local climate.

2. The result of evolutionary adaptation* will (partly) determine what happens to populations given climate change.

3. A relevant management of the genetic variability may positively influence how population respond and adapt to climate change.

** Evolutionary" adaptation : the process whereby an organism becomes better suited to its environment.*

Are forest trees able to naturally adapt to future climate?
Evolutionary dilemmas in the face of climate change

- Extinction of local population
- Migrate to new (better suited) habitats
- Acclimate by modifying individuals to new environment (phenotypic plasticity) and evolve through natural selection of better suited individuals

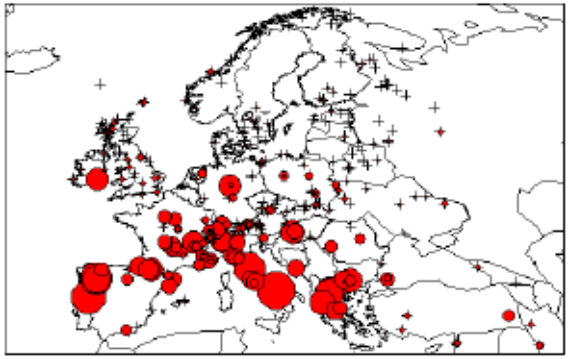
1- Disappear : *Lessons from the past*

Sessile Oak

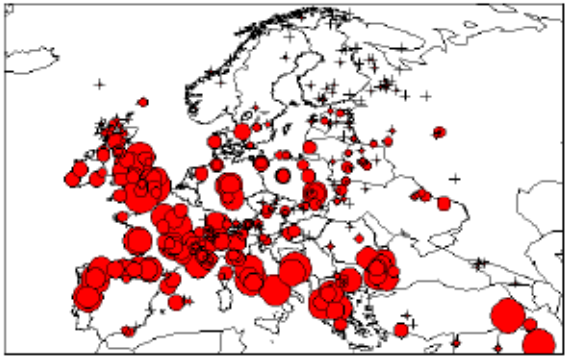
Brewer et al. Forest Ecology and Management 2002

15 000 BP

13 000 BP



9 000 BP



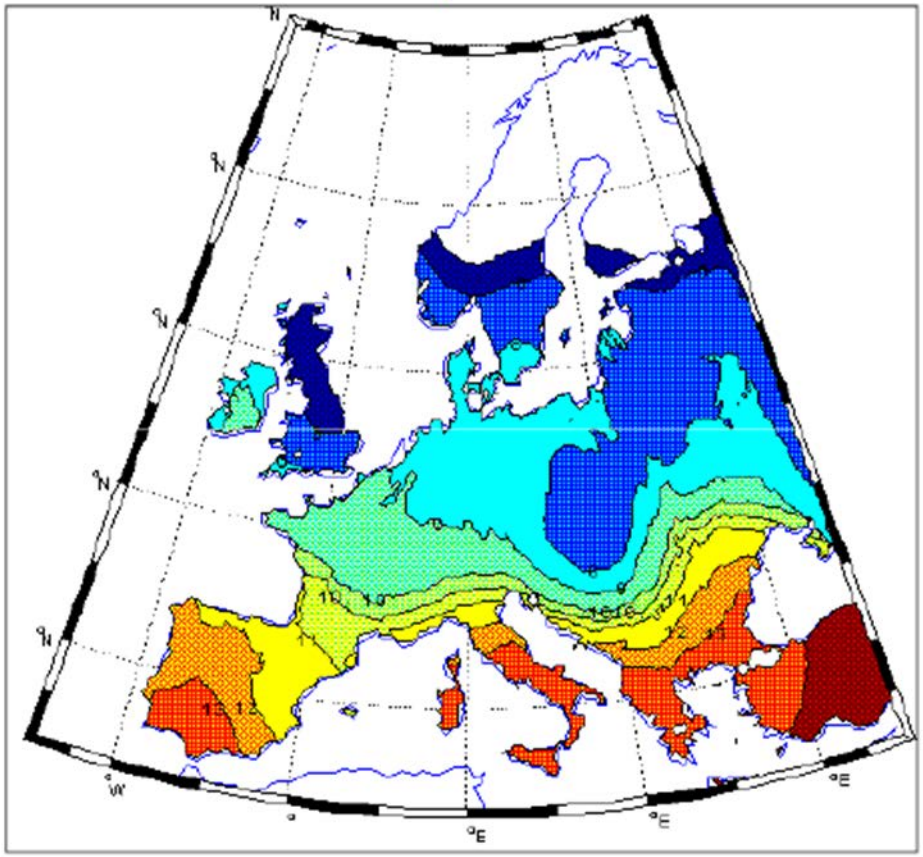
6 000 BP

- Few extinctions at the south margins of natural areas
- Strong differentiations among populations
- Significant lost of genetic diversity within populations

2- Migrate : *a realistic solution?*

Sessile Oak

Post glacial migration ≈ 400 meters/yr.



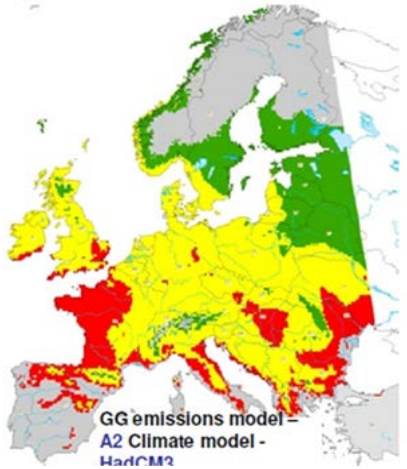
European Pollen Database,
Univ. Aix-Marseille

Brewer et al, Forest Ecology and Management 2002

Migration required to reach the predicted bioclimatic envelopes in 100 years ≈ 5 to 7 km/yr.

Sessile Oak

Today



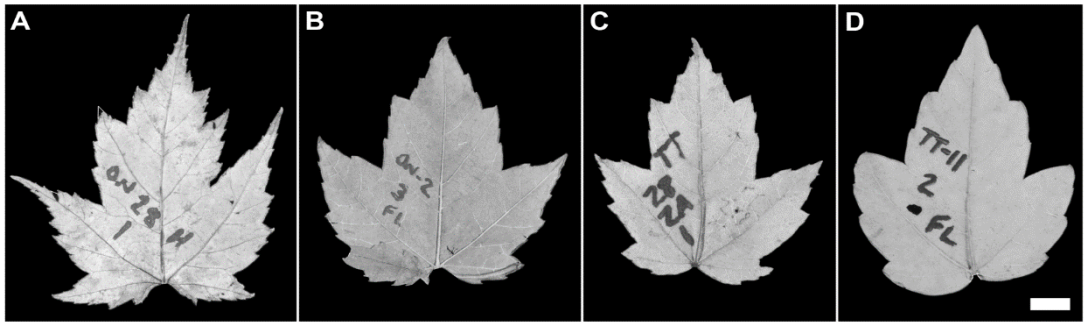
Sessile Oak

2080

3- Acclimate & Evolve

A short term solution : the phenotypic plasticity

- Phenotypic plasticity = the ability of an individual to change its characteristics (phenotype) in response to changes in the environment
- Phenotypic plasticity is common in plants. Plants modify their phenology and growth in response to changes in environments
    - Bud-set
    - Bud-burst
    - Flowering
    - Acclimation to drought



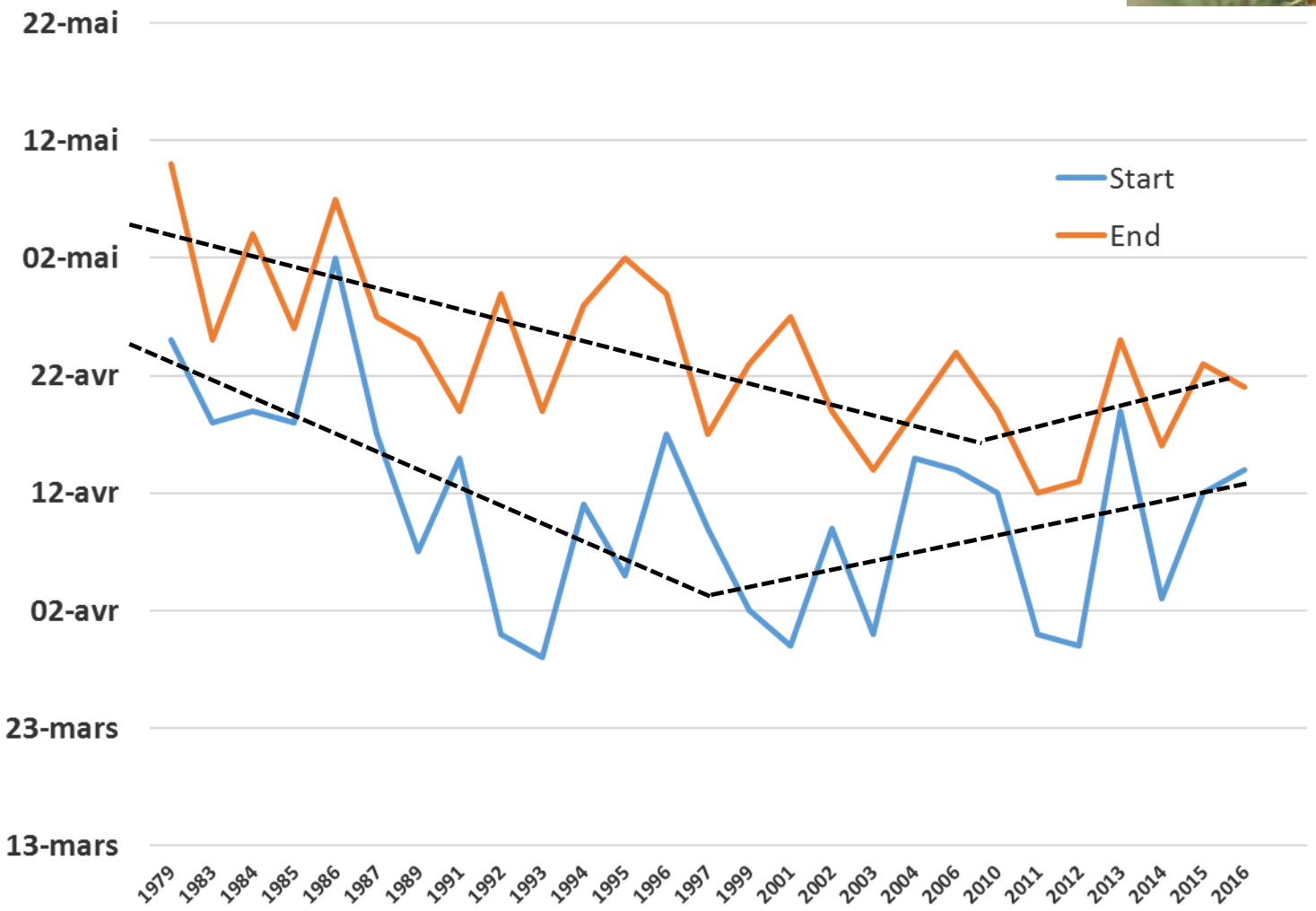
Acer rubrum – *Royer et al 2009 Plos One*

Temperature

Visible impacts of CC on trees

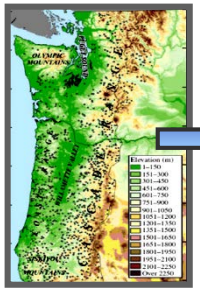
- Variations of Douglas-fir floral phenology

Evolution of start and end flowering dates in Orléans



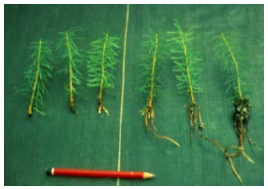
Evidence for plasticity comes from common garden (provenance) studies

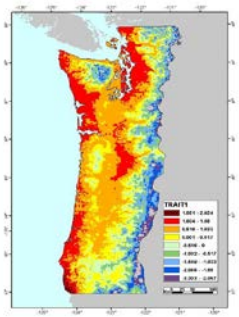
Seed sampling in various environments of the natural range



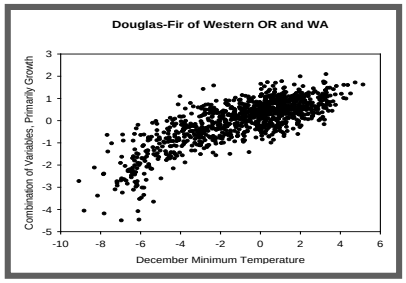
Grow provenances / families in several common environments

Measure many adaptive traits





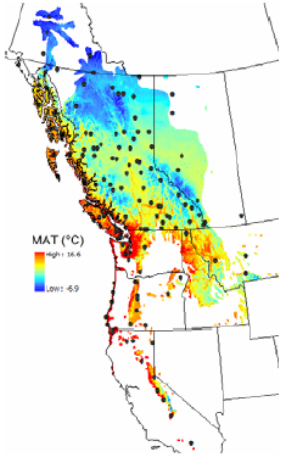
GIS



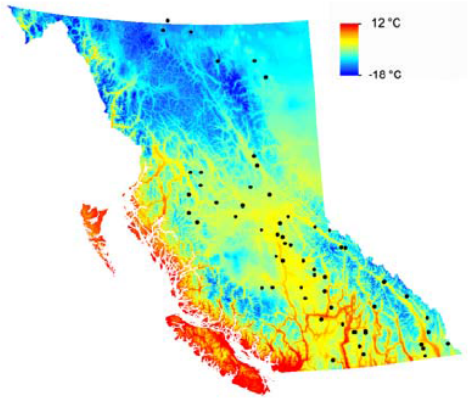
Analyze trait /climate relationships

Climate change effect on lodgepole pine *(P. contorta)*

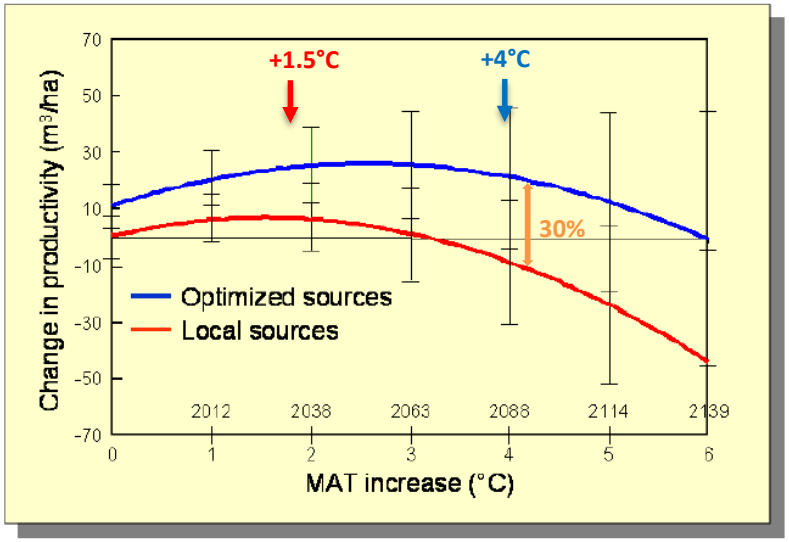
Wang et al. (2006) Global Change Biol. 12:2404-2416



140 populations



60 test sites

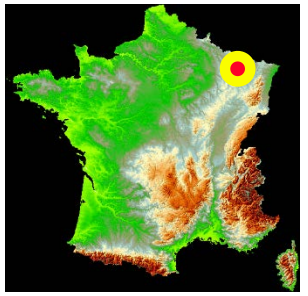


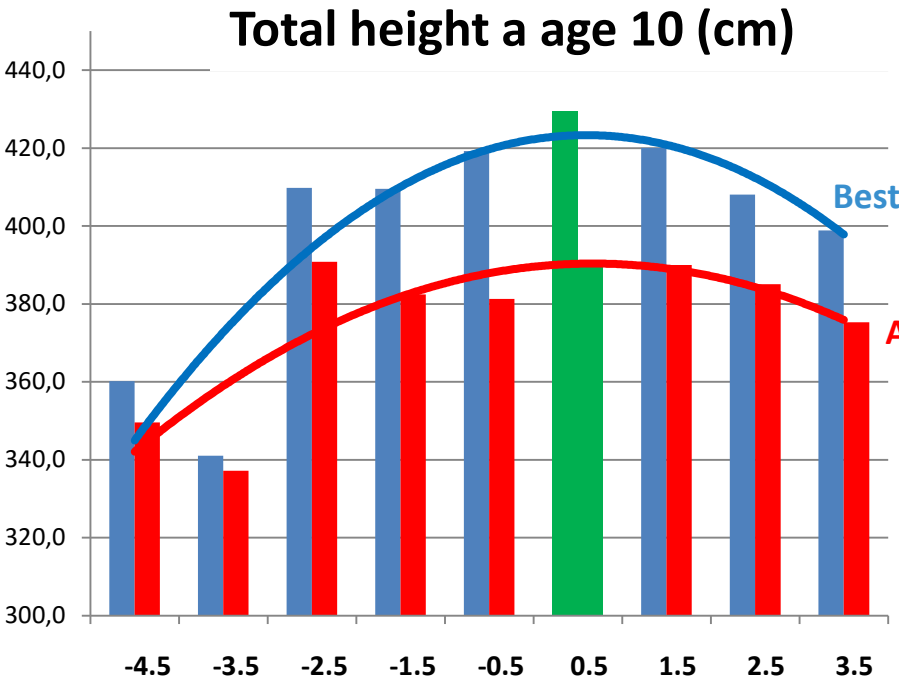
Local source : Productivity increases by 7% up to + 1.5°C (2030) but decreases above 2°C

Optimal source : Productivity increases by 14-36%

Climate change effect on sessile Oak *(Q. petraea)*

(A. Ducousso)





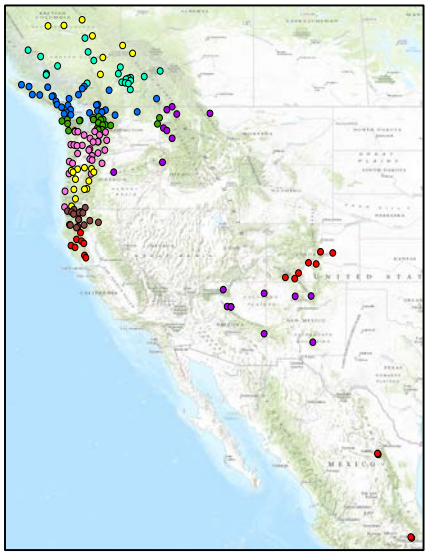
Difference in mean annual **temperature** between trial site and provenance (°C)

+0.5 to 1 °C

Climate change effect on Douglas fir *(P. menziesii)*

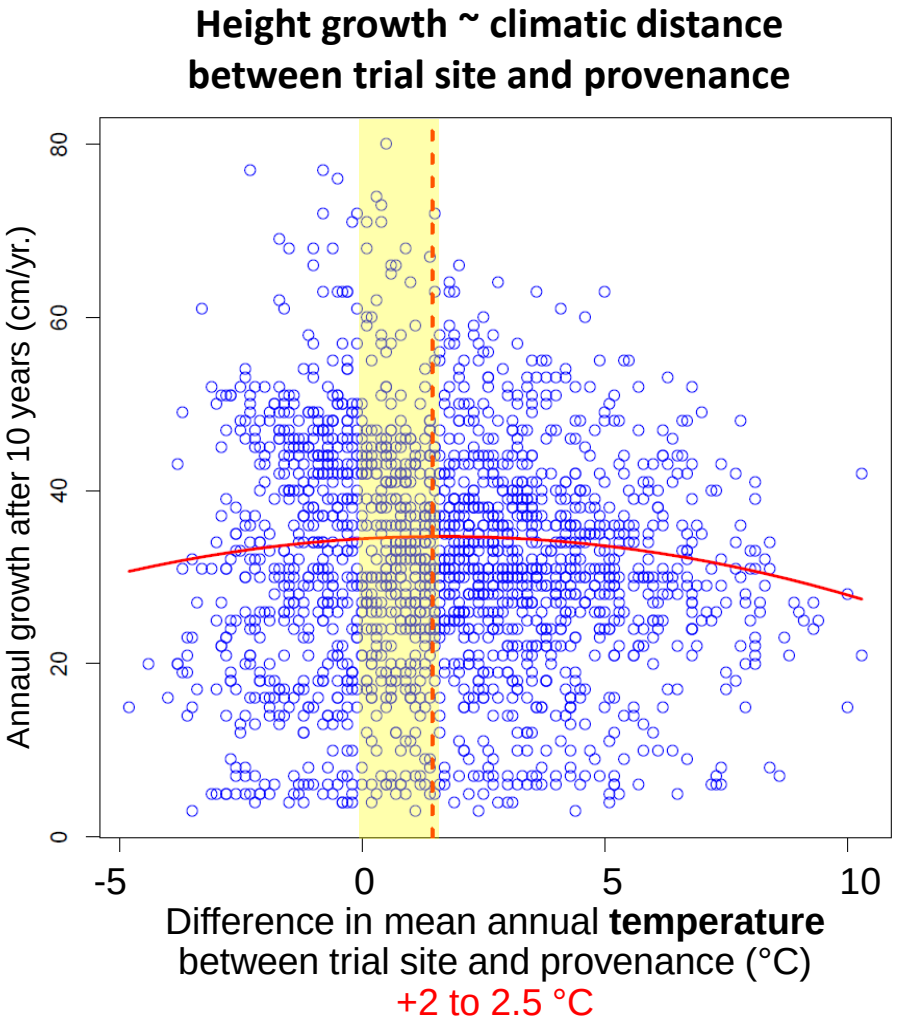
(J. Boiffin & V. Badeau, 2016)

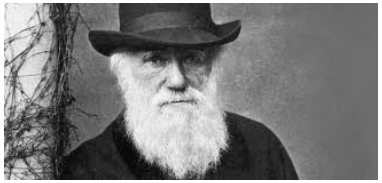
180 populations
8 bioclimatic groups



88 test sites
10 bioclimatic groups

Population effect (age 10 - 14)



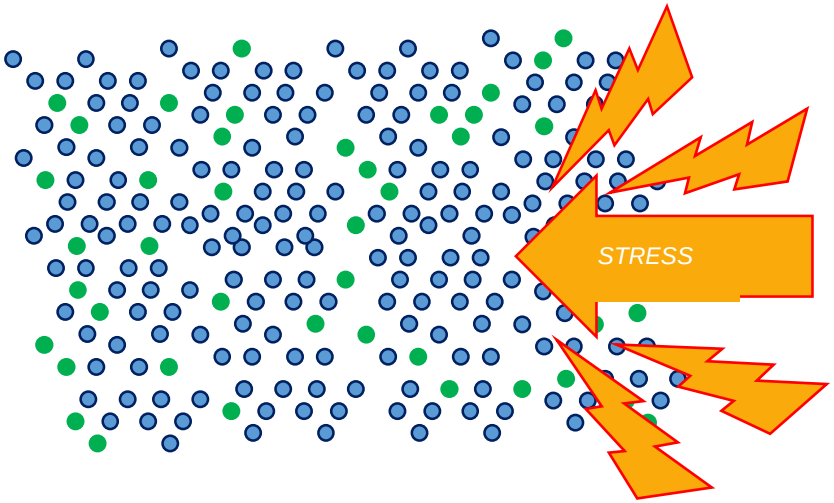


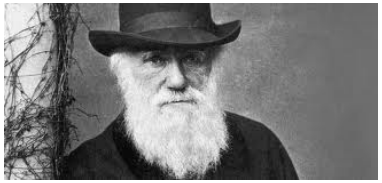
3- Acclimate & Evolve

A long term solution : the genetic adaptation

"Evolution through natural selection "

Possible if genetic diversity is broad enough, but requires several generations





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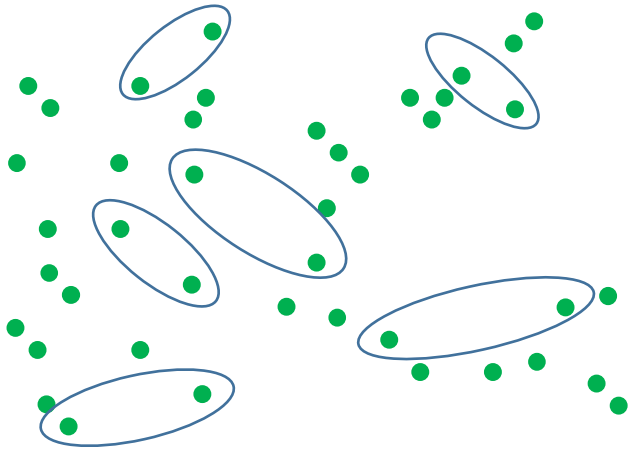
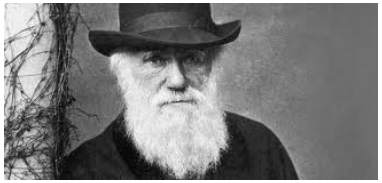


Partial survival:

Reproduction between surviving trees



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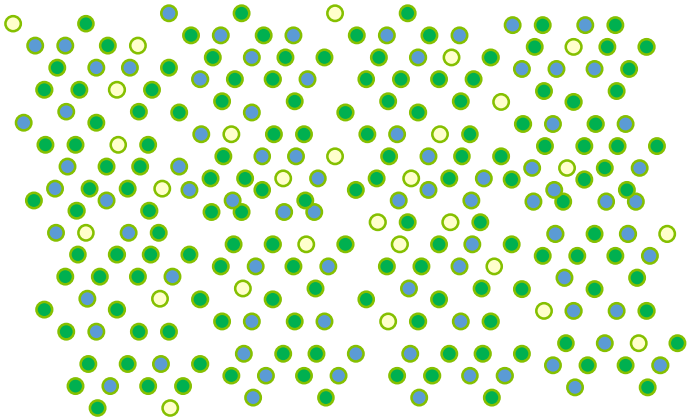
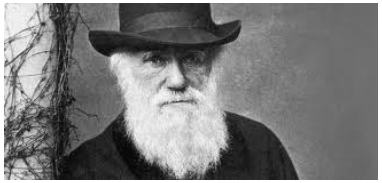


Partial survival:
Reproduction between surviving trees

New stand (a priori better suited)

Important factors include:

- Central vs peripheral populations
- Trailing edge vs leading edge
- Levels of gene flow
- Mating system
- Population size
- Phenotypic variation
- Heritabilities
- Genetic correlations
- Intensity of selection/fecundity
- Generation turnover
- Biotic interactions



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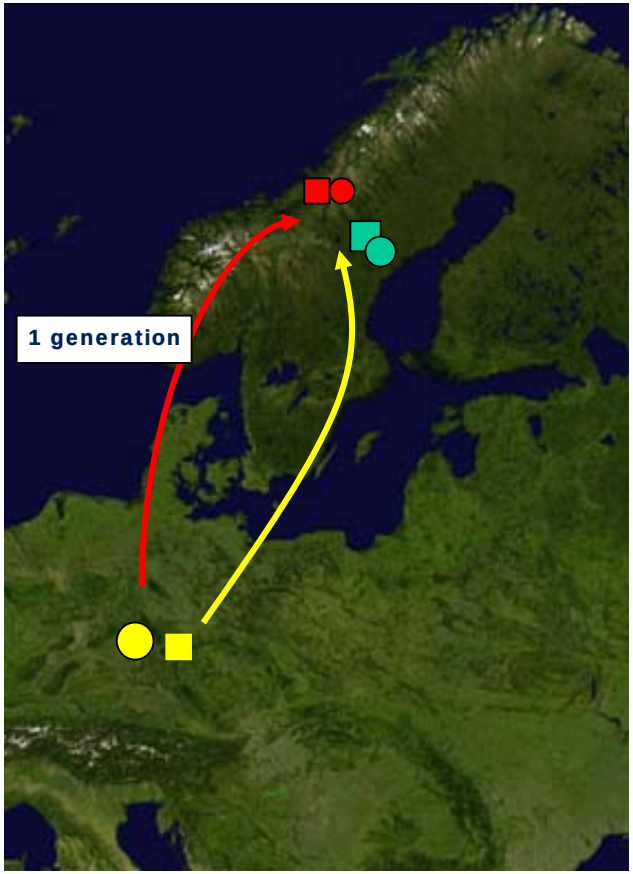
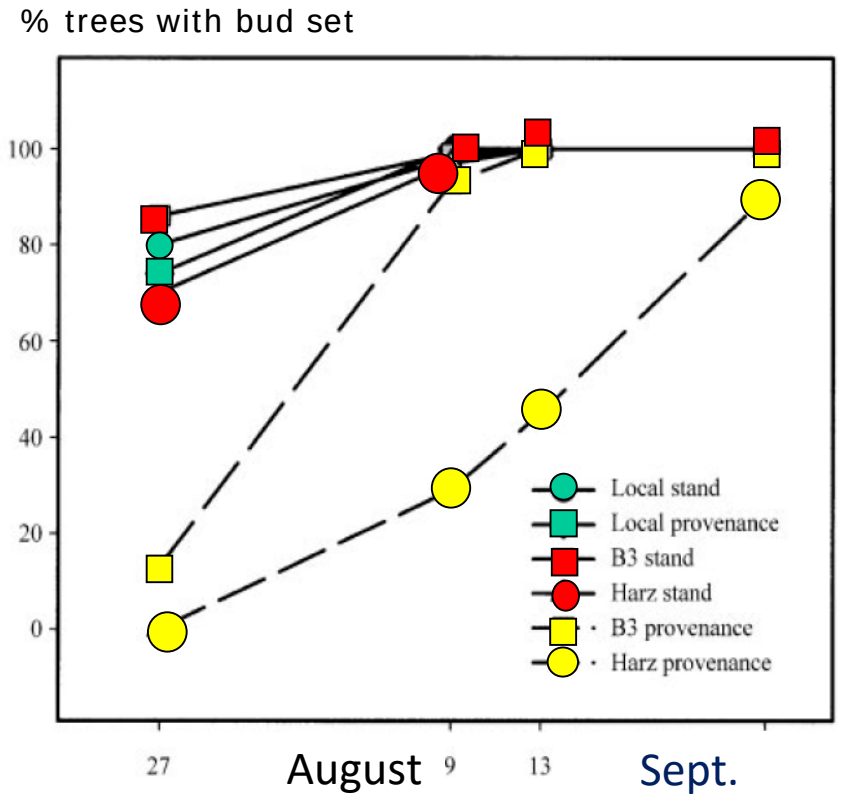
A long term solution : the genetic adaptation

… has been effective in 1 generation



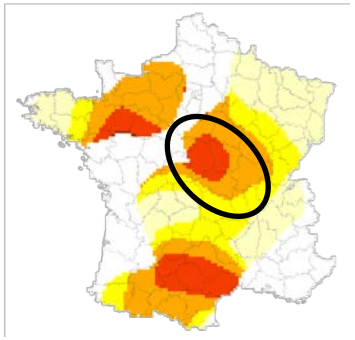
Norway Spruce



Skroppa & Kohmann, 1997 Forest Genetics 4:171-177

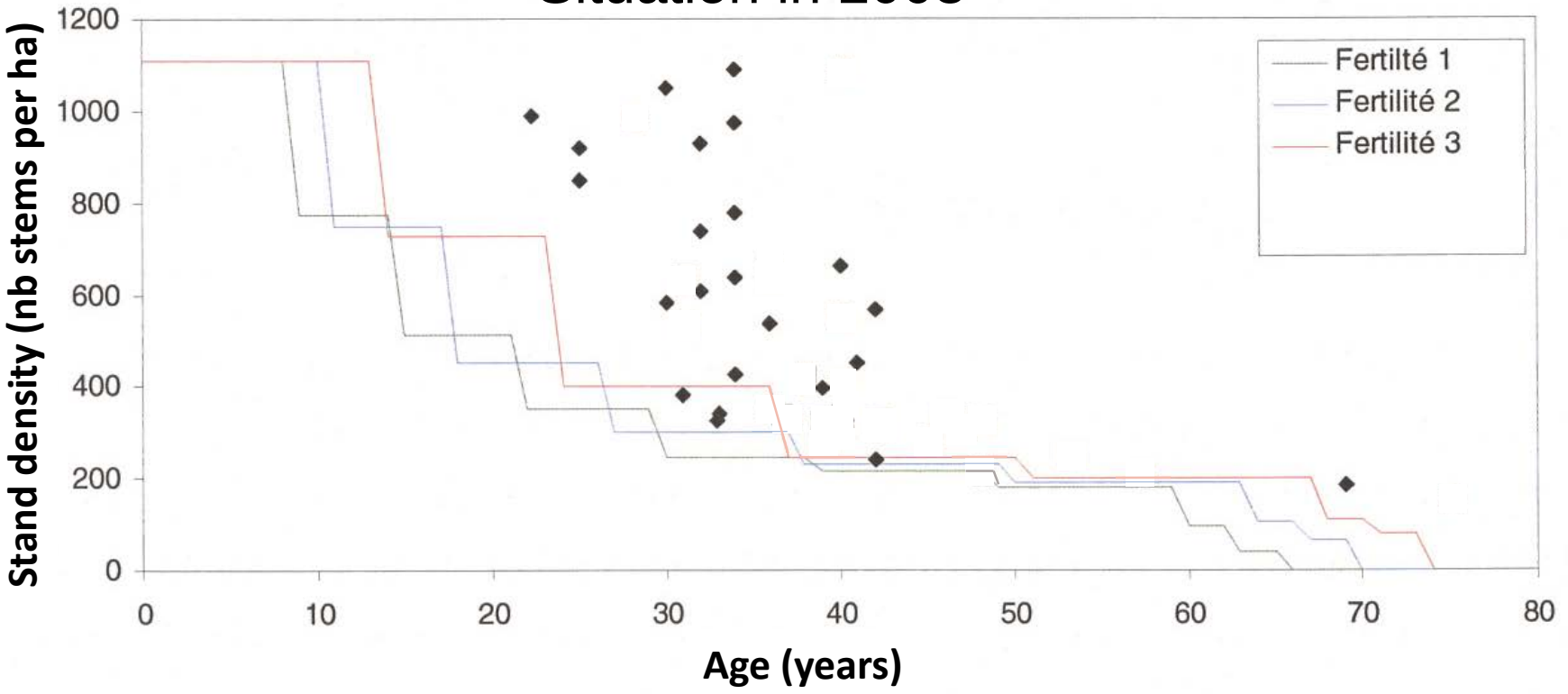
What can we do to help forest trees adapt to future climate ?

1. Adapt silviculture *(densities, thinnings, rotations)*



Stem density of 25 Douglas-fir stands in Burgundy
vs recommended silvicultural itineraries

Situation in 2003



Anne Sophie Sergent, 2011

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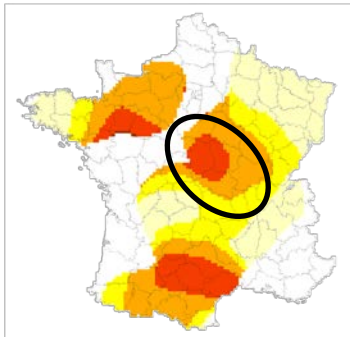
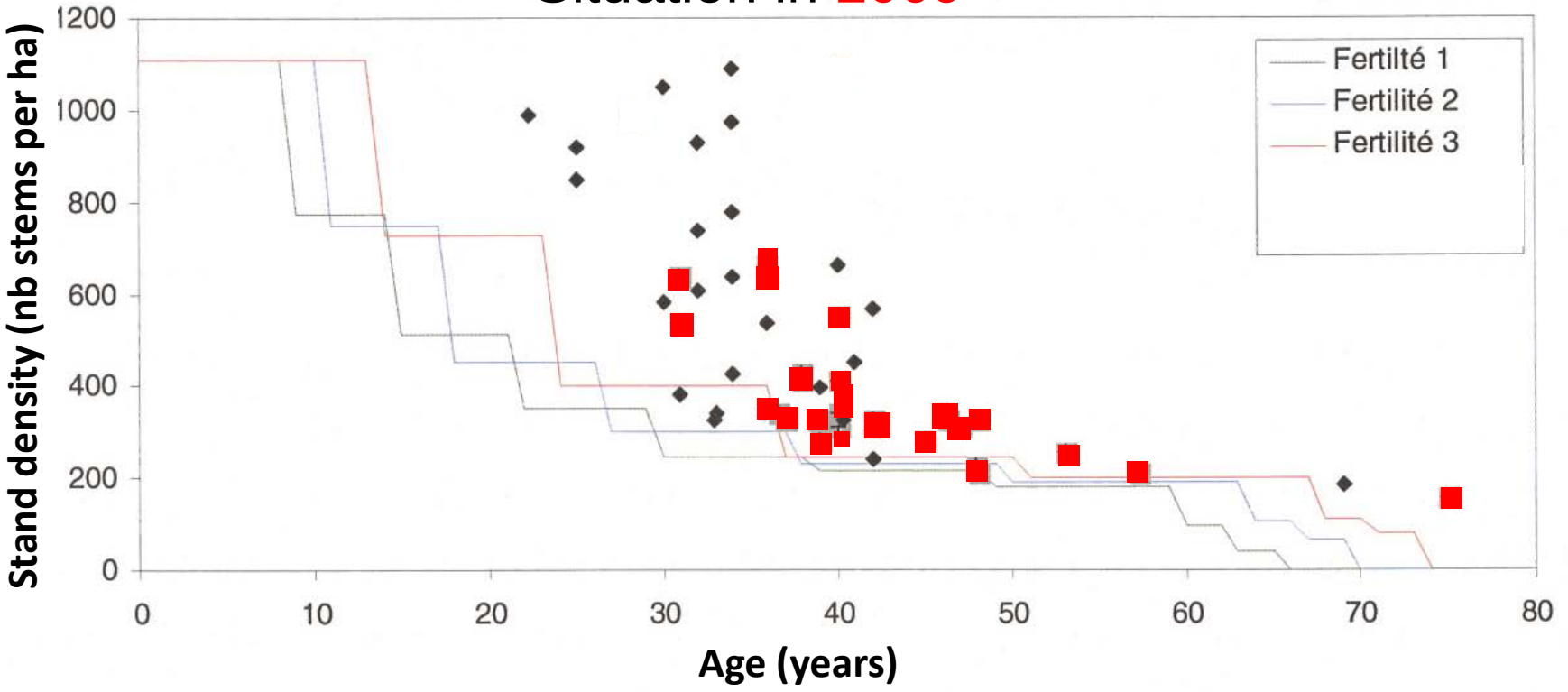


Stem density of 25 Douglas-fir stands in Burgundy
vs recommended silvicultural itineraries

Situation in 2009



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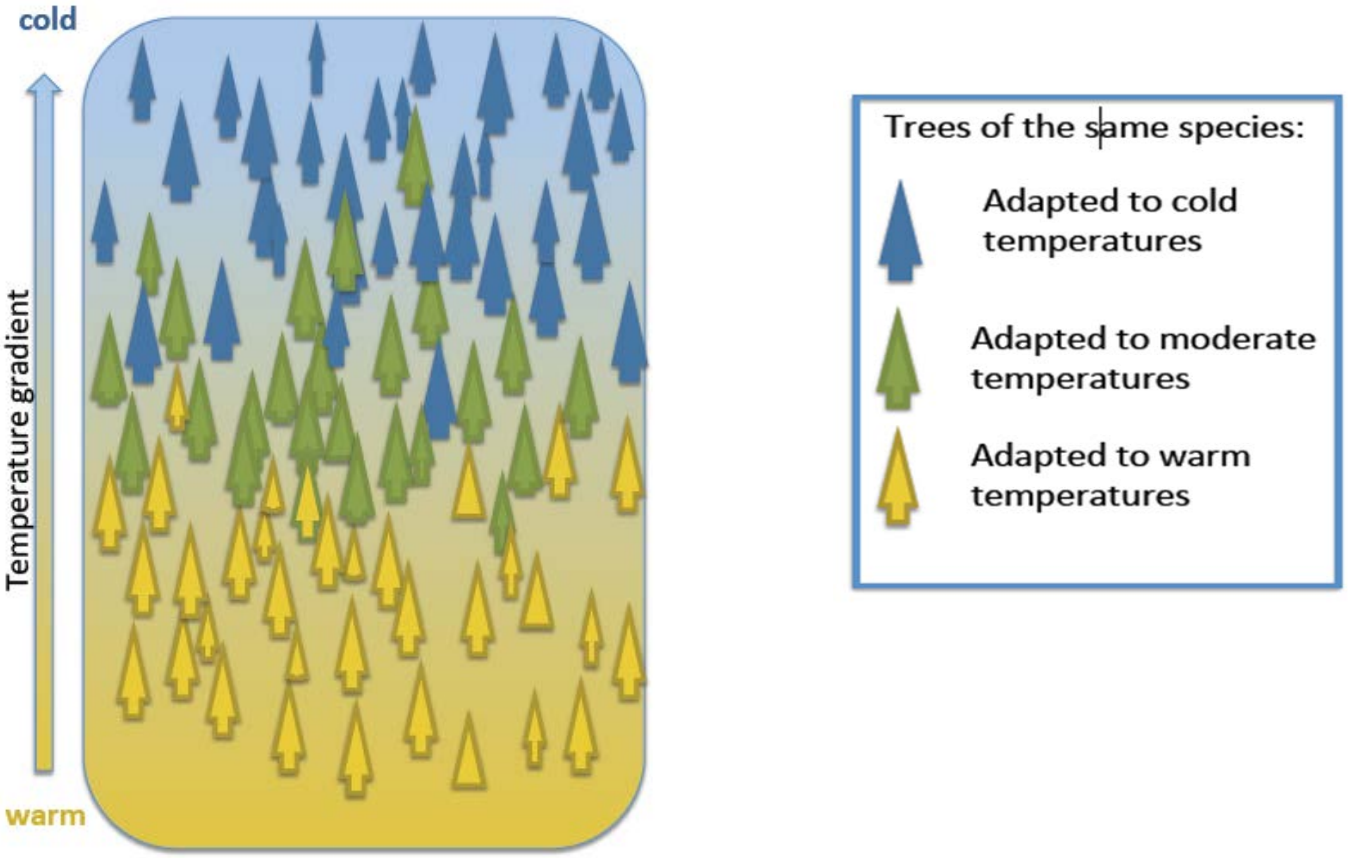

From Aitken 2012

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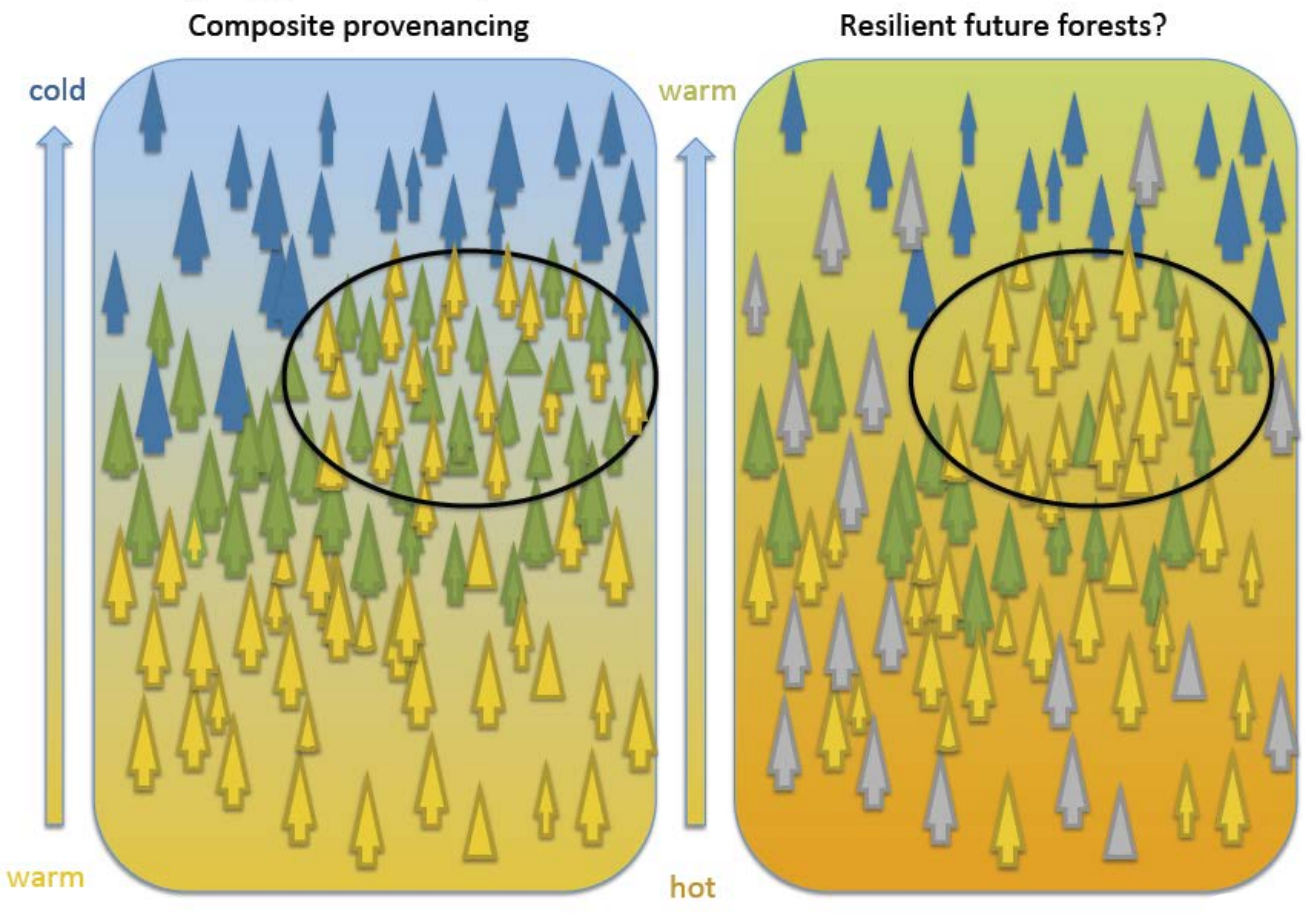

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What can we do to help forest trees adapt to future climate ?

1. Adapt silviculture *(densities, thinnings, rotations)*
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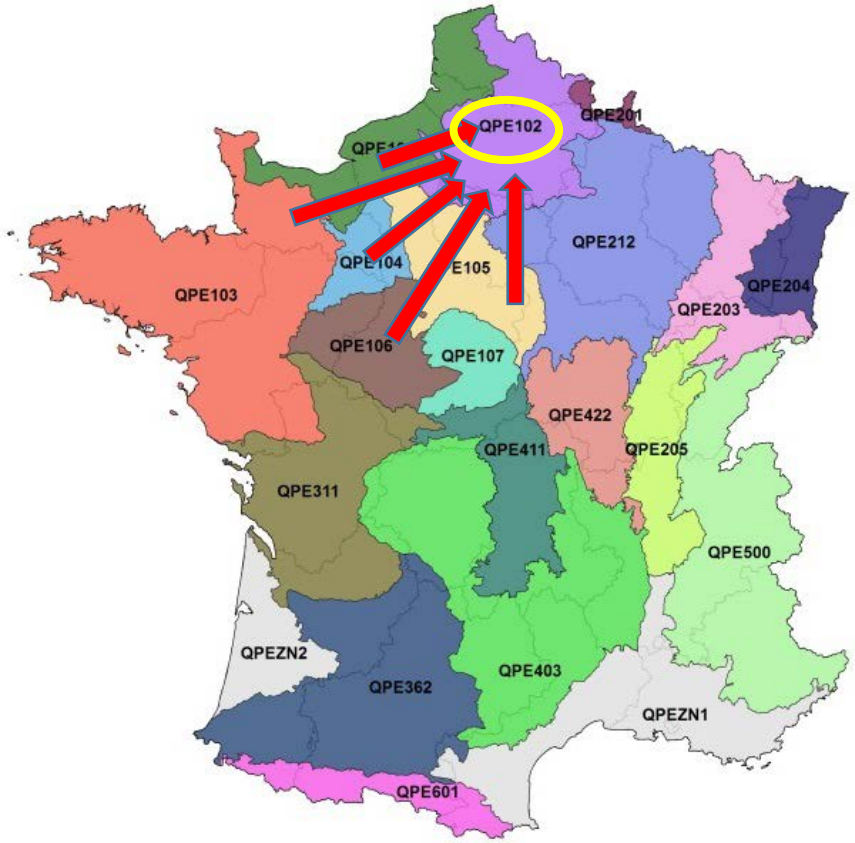
3. Create transfer decision-support tools to help foresters select seed lots that are adapted to future climates at their sites

Updated French guidelines on FRM deployment in the context of climate change

Sessile Oak (*Quercus petraea*)



Areas of use / Seed zones		Recommended materials		Other usable materials	
Code	Name	Name	Cat.	Name	Cat.
QPE101	Bordure Manche	QPE101	S	QPE102, QPE103*, QPE104*, QPE105*, QPE106*	S
QPE102	Picardie	QPE102	S	QPE101, QPE103*, QPE104*, QPE105*, QPE106*	S
QPE103	Massif armoricain	QPE103	S	QPE104, QPE106,	S
QPE104	Perche	QPE104	S	QPE106, QPE107*, QPE311*	S
QPE105	Sud Bassin parisien	QPE105	S	QPE102, QPE106*, QPE107*, QPE411*	S
QPE106	Secteur ligérien	QPE106	S	QPE104, QPE107*, QPE311*, QPE411*	S

http://agriculture.gouv.fr/graines-et-plants-forestiers

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2. Move populations to new sites where they are expected to be better adapted in the future.
3. Create transfer decision-support tools to help foresters select seed lots that are adapted to future climates at their sites
4. Practice selection and breeding for adaptive characteristics
   - *Assess provenances and varieties for their sensitivity to CC*
   - *Breed for adaptive traits* *(drought hardiness, tolerance to pests, xylem cavitation)*

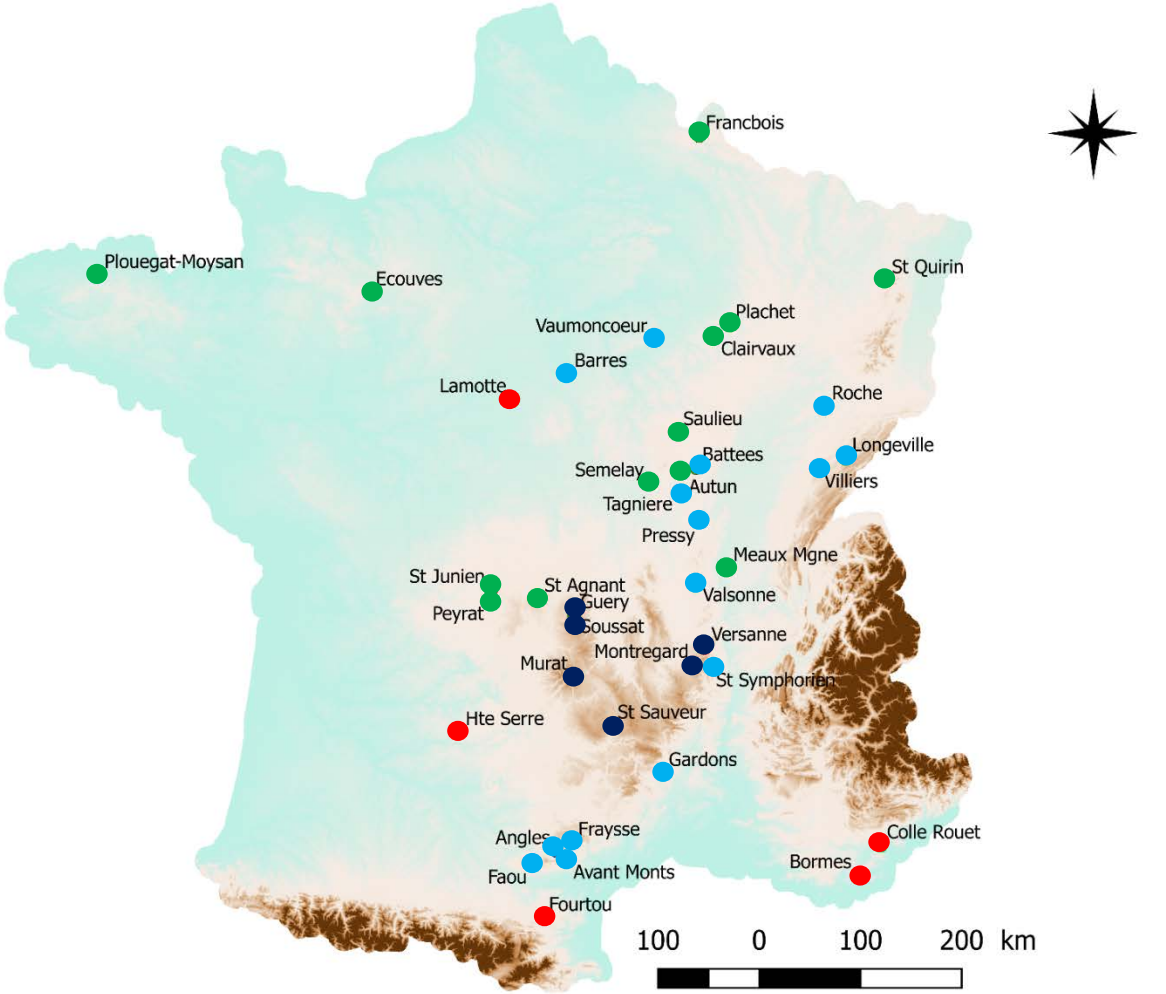
Evaluate the sensitivity of varieties to climate change

French Douglas-fir seed orchard evaluation network

8 Douglas-fir seed orchards
43 tests planted 2009 to 2016

Test site's environments

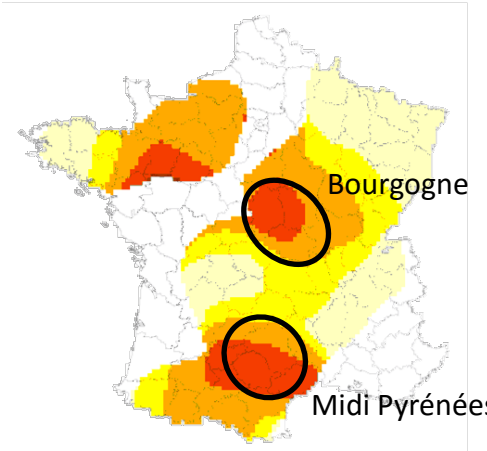
- Area's heart (ok/ok)
- Margin 1 (ok/?)
- Margin 2 (no/no)
- Altitude (no/ok)

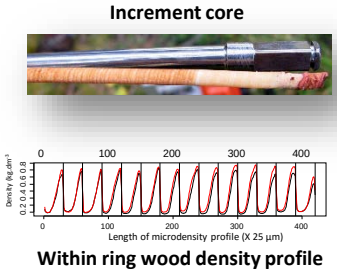


Identify traits related to adaptation & plasticity

Wood density : a predictor of resistance to drought in Douglas fir

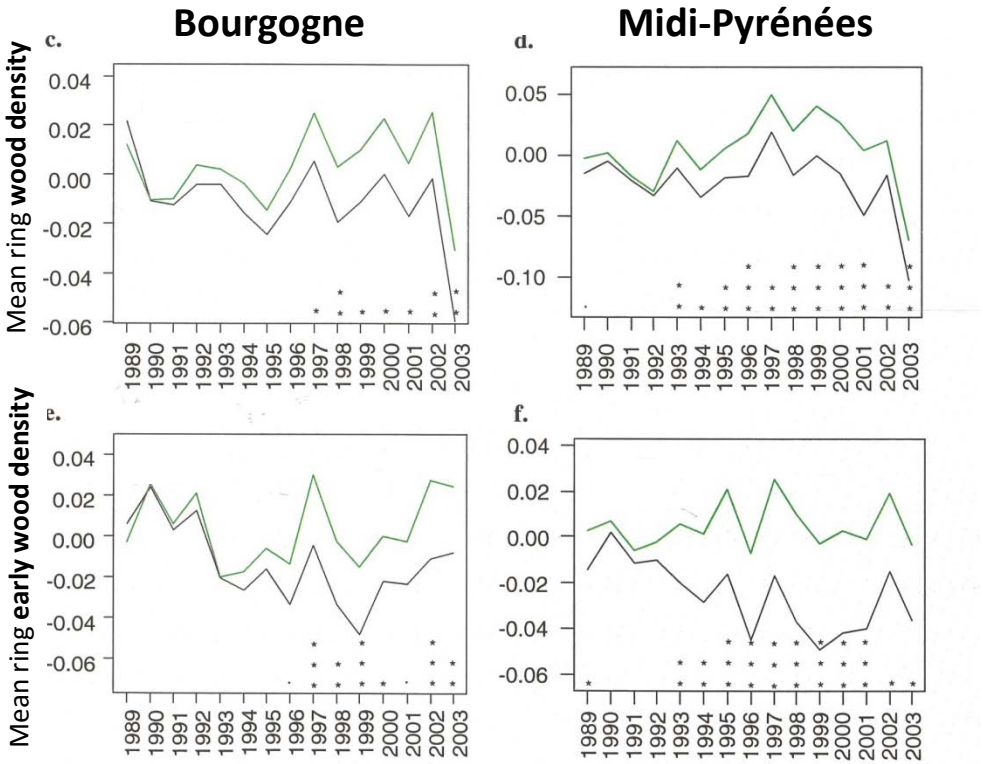
(Manuela Ruiz Diaz, Anne-Sophie Sergent, Alejandro Martinez Meier, Nathalie Bréda, and Philippe Rozenberg)





15 plots (700 m^2) in 2 regions
30 trees / plot
- *15 surviving*
- *15 dead / decaying*

→ 900 trees



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4. Practice selection and breeding for adaptive characteristics
   - *Assess provenances and varieties for their sensitivity to CC*
   - *Breed for adaptive traits (drought hardiness, tolerance to pests, xylem cavitation)*
5. Conserve genetic diversity
6. Test new species

Summary & conclusion

1. How are plants adapted to their local climates?

- In their history, trees have experienced recurring major environmental changes
- Trees have developed evolving mechanisms that have enabled them to adapt:
  - *phenotypic plasticity*
  - *maintenance of high genetic diversity*
  - *important gene flows*

2. Will plants naturally adapt to future climates?

- These mechanisms are and will be solicited by ongoing climate change
- Phenotypic plasticity & migration rates do not appear to be sufficient

3. What can we do to help plants adapt to future climates ?

- Management options exist for helping plants adapt to climate change, these include : *assisted migration, enhancing genetic diversity, selection and breeding, ….*
- **Planting** is an option to consider for renewing the forest in a context of rapidly changing climatic and economic contexts.

Thank you for your attention.